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Variation in Early Plant Height in Wild Soybean

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ABSTRACT

It is difficult to evaluate plant height at maturity in wild soybean (*Glycine soja* Sieb. & Zucc.) and no research about plant height at early growth stages has been reported. The objective of this study was to identify variation for plant height at early growth stages in wild soybean accessions. On the basis of the data collected in 1999, five accessions were selected from each height class (tall, intermediate, and short) for each of three maturity groups (00, II, and IV). These 45 accessions were planted in a completely randomized design with six replications in 2000 and 2003. Three height measurements (H1, H2, and H3) were taken at 10-d intervals beginning 20 d after planting. A multiple comparison *t* test by Fishers Least Significant Differences (LSD) was used to test the differences among means of three early plant height classes. Highly significant differences were found among years, height classes, accessions within height classes and within maturity groups, and year × accession interaction for H2 measurement, but there were no significant differences among maturity groups and no significant interaction between year and height classes. The optimum time for evaluating differences in early plant height is 30 d after planting. This rapid growth trait in wild soybean could be beneficial for cultivated soybean and a useful trait for evaluating wild soybean germplasm.

Plant height is an important characteristic in soybean germplasm and cultivar evaluation. Most current commercial soybean cultivars are less than 1 m tall measured as the length of the main stem from the soil surface to the terminal node at maturity. Within the USDA Soybean Germplasm Collection, there are soybean accessions with mature plant heights of less than 30 cm or greater than 2 m when grown at optimum latitudes. A number of researchers (Keim et al., 1990; Mansur et al., 1993; Lee et al., 1996a; Mansur et al., 1996) have identified quantitative trait loci (QTL) for plant height at maturity in soybean. Lee et al. (1996b) in their study on molecular markers associated with soybean plant height across locations found that 11 independent restriction fragment length polymorphism (RFLP) markers associated with plant height explained most of the genetic variability for this trait in combined analysis across locations.

For several reasons, it is very difficult to obtain mature plant height in wild soybean. Wild soybean stems are twining and viney, and oftentimes there is no main stem. At maturity, the slim stem is very fragile and easily broken. There are no records of plant height for the 6172 accessions of Chinese wild soybean collection (Li, 1990, 1994). For 200 wild soybean accessions in maturity groups 000 to IV from the USDA wild soybean collection previously evaluated, mature plant heights were documented between 15 cm (PI 464866B) and 146 cm (PI 366121) (Juvik et al., 1989). These accessions were grown in an environment in which disease and insect damage significantly affected the growth of most accessions.

Mian et al. (1998) used 142 RFLP markers and 116 F_2–derived lines from a cross of ‘S-100’ × ‘Tokyo’ to map QTL conditioning soybean plant height and canopy width during early growth stages. They found three and four independent RFLP loci were associated with plant height at the V7 and V10 stages, respectively. ‘Spry’ is a soybean cultivar with rapid early-season growth (Bernard and Nickell, 1992). Spry has determinate stem termination but has rapid early-season growth, and the final plant height (approximately 90 cm) is almost equal to indeterminate cultivars of similar maturity such as ‘Flyer’, ‘Hamilton’, and ‘Pharaoh’ (Wilcox, 1992). There is no published research about plant height in early growth stages of wild soybean. The objective of this study was to identify variation for plant height at early-growth stages in wild soybean accessions.

MATERIALS AND METHODS

All 468 wild soybean accessions from USDA Soybean Germplasm Collection in maturity groups 000 through IV were planted in unreplicated hill plots inside aphid-proof cages at Urbana, IL, in 1999. Wild soybean accessions are grown in aphid-proof cages at Urbana to prevent damage from insects and vector borne diseases, especially viruses. This permits a better evaluation of morphological traits than was previously possible. Seeds were scarified by soaking for 15 min in concentrated sulfuric acid, followed by a water rinse and air-drying before planting. A tripod 120 cm high was erected over each hill to support the plants. Plant height was measured on all plots 30 d after planting.

On the basis of the data collected in 1999, five accessions were selected from each height class (tall, intermediate, and short) for each of three maturity groups (00, II, and IV). (Table 1). The 45 selected accessions were planted in an aphid-proof cage on 26 May 2000 at Urbana, IL. The experiment was a completely randomized design with six replications of individual plants. The individual plants were grown in a space 30 × 50 cm. A 240-cm bamboo pole was erected by each single plant for support. Three height measurements (H1, H2, and H3) were taken at 10-d intervals from 20 to 40 d after planting

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Abbreviations: DAP, Days After Planting; HC, Height Class; LSD, Fisher’s Least Significant Differences; MG, Maturity Group; PI, Plant Introduction; QTL, quantitative trait loci; RFLP, restriction fragment length polymorphism.

Table 1. Origin, maturity group and early plant height data for 44 selected wild soybean accessions.

Accession	Origin	MG	MD†	Height class‡	1999 Height H2	2000 Height§ H1	2000 Height§ H2	2000 Height§ H3	2003 Height H2
					cm	cm	cm	cm	cm
PI 423998	Russia	00	81	short	15	12	64	123	25
PI 464868B	Heilongjiang, China	00	81	short	17	14	63	118	52
PI 423995	Russia	00	81	short	21	12	56	104	44
PI 458540D	Heilongjiang, China	00	81	short	25	11	51	99	56
PI 507836	Russia	00	82	short	21	12	56	93	50
PI 424002	Russia	00	81	intermediate	42	22	78	114	64
PI 507727	Russia	00	81	intermediate	45	15	64	102	43
PI 424000	Russia	00	81	intermediate	48	22	78	146	23
PI 507734	Russia	00	82	intermediate	40	11	54	116	56
PI 507847	Russia	00	83	intermediate	44	24	83	132	60
PI 507841B	Russia	00	76	tall	60	23	78	134	74
PI 507760	Russia	00	76	tall	68	22	77	130	68
PI 507757	Russia	00	82	tall	57	24	79	125	85
PI 507749	Russia	00	82	tall	60	15	63	105	62
PI 507730	Russia	00	81	tall	57	19	76	118	75
PI 479750	Jilin, China	II	115	short	7	9	40	85	46
PI 479745	Jilin, China	II	112	short	15	6	35	75	33
PI 101404B	Heilongjiang, China	II	115	short	4	10	49	86	58
PI 326582A	Russia	II	118	short	5	23	69	99	44
PI 407296	Liaoning, China	II	118	short	8	14	62	114	56
PI 464891B	Jilin, China	II	117	intermediate	45	20	60	101	51
PI 479746B	Jilin, China	II	112	intermediate	45	14	75	141	59
PI 407298	Liaoning, China	II	115	intermediate	45	16	74	129	74
PI 522194B	Russia	II	115	intermediate	46	22	76	112	51
PI 507799	Russia	II	110	intermediate	45	17	66	104	57
PI 468918	Liaoning, China	II	114	tall	80	45	88	142	70
PI 522212B	Russia	II	115	tall	75	36	95	130	57
PI 522214B	Russia	II	117	tall	72	34	75	120	81
PI 507794	Russia	II	117	tall	80	31	87	138	73
PI 507782	Russia	II	112	tall	80	30	76	112	74
PI 464938	Jiangsu, China	IV	143	short	22	10	58	94	49
PI 407200	S. Korea	IV	142	short	10	7	27	85	43
PI 407217	S. Korea	IV	142	short	18	6	18	73	27
PI 366120	Japan	IV	143	short	5	6	23	76	72
PI 468396B	Shanxi, China	IV	143	short	17	7	41	83	38
PI 407278	S. Korea	IV	142	intermediate	45	13	58	87	67
PI 407275	S. Korea	IV	142	intermediate	42	9	45	94	32
PI 424088	S. Korea	IV	142	intermediate	44	19	66	106	89
PI 366123	Japan	IV	140	intermediate	42	22	70	105	66
PI 339732	S. Korea	IV	143	intermediate	50	12	66	96	59
PI 407162	S. Korea	IV	146	tall	60	35	98	125	91
PI 407032B	Japan	IV	146	tall	66	34	76	127	110
PI 366121	Japan	IV	152	tall	63	17	81	122	72
PI 366122	Japan	IV	152	tall	72	37	100	131	48
$LSD_{0.01}$						9.5	17.3	32.8	12.2

† Maturity date recorded in 2000. The maturity date was determined when eighty percent of pods were ripe.
‡ 1999 data.
§ Three height measurements (H1, H2, and H3) were taken 20, 30, and 40 d after planting, respectively.

(DAP). Before the measurements, all stems were straightened to obtain accurate data, and after the measurements, the stems were re-twisted around the supporting stakes. The experiment was repeated in May 2003 at Urbana, IL, but height was measured only 30 DAP (H2).

The GLM procedure of SAS (SAS Institute, 1999) was used to analyze the data collected in 2000 and 2003. Entries were considered fixed effects and so maturity groups and early plant height were also fixed effects. A nested design was used with entries nested within height classes and maturity groups. Fisher's Least Significant Differences (LSD) at 1% significance level was used to test for differences among height classes and maturity groups.

Three regression models were tested for growth patterns within each height class. A linear regression model, $Y = \beta_0 + \beta_1 X$, was tested where β_0 is the intercept, β_1 is the regression coefficient, Y is the plant height, and X is the days after planting. A one-variable polynomial model defined as follows $Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \ldots + \beta_m X^m + \varepsilon$ was tested. The highest power of X used in the model is known as the degree of the model, but the optimum degree of the model is unknown until a satisfactory degree of fit has been accomplished. Mathematical biologists have developed many sophisticated models to fit growth curves. One of the commonly used models is known as the Logistic Growth Curve with three parameters (Freund and Littell, 1991). The general form of the equation for the curve is $Y = \frac{b_1}{1+[(b_1 - b_2)/b_2]e^{-b_3 X}} + \varepsilon$, where b_1 is the height of the horizontal asymptote at a very large X, b_2 is the expected value of Y at time $X = 0$, b_3 is a measure of growth rate, and ε is the random error. The residual sum of squares of each model was used to determine how well each model fit the data.

RESULTS AND DISCUSSION

The variation in early height among wild soybean accessions was obvious in 1999 (Table 1). Heights ranged from 4 cm (PI 101404B) to 80 cm (PI 468918, PI 507782, and PI 507794). The range of the height within each maturity group was very similar, indicating that there was no relationship between early plant height and maturity.

Table 2. Mean values for each plant height class by maturity groups and for all accessions at each measurement.

Measurement†	Height class	All accessions	MG 00	MG II	MG IV
		cm			
H1	tall	29 A‡	20 A	35 A	31 A
	intermediate	17 B	19 A	18 B	15 B
	short	11 C	13 B	13 C	7 C
H2	tall	78 A	74 A	78 A	84 A
	intermediate	62 B	61 B	64 B	62 B
	short	46 C	51 C	50 C	40 C
H3	tall	126 A	122 A	128 A	126 A
	intermediate	112 B	121 A	117 A	98 B
	short	94 C	107 A	92 B	82 C

† Three height measurements (H1, H2 and H3) were taken 20, 30, and 40 d after planting, respectively. H2 was the mean of 2000 and 2003 data.
‡ Overall means or means within maturity groups and measurement date with the same letter are not significantly different (0.01 probability level).

Forty-five wild soybean accessions were grown in an aphid-proof cage in 2000 and 2003 to verify the difference in early plant height among wild soybean accessions, but only data from 44 accessions could be used in the final statistical analysis. Highly significant differences were found among years, height classes, accessions within height classes, and maturity groups, but there were no significant differences among maturity groups for H2 measurements. The years × accessions interaction was significant for H2 measurements, but there was no significant interaction between years and height classes. The mean square for the main effect of years was 5-times larger and the mean square for height classes was nearly 40-times larger than the mean square for the interaction between years and accessions. There were inconsistencies in early plant height between years for some accessions (Table 1) but those differences were much smaller than the differences associated with years and height classes. The means of the three height classes at all three measurements (H1, H2, and H3) were highly significantly ($p = 0.01$) different for maturity group IV lines and for the means over all maturity groups (Table 2). Within maturity group II lines, the means of the three height classes were significantly different for H1 and H2, but the tall and intermediate classes were not significantly different for H3. No differences were detected between the tall and intermediate classes for H1 and H3 for maturity 00 lines, but significant differences were detected for H2 and between the short class and tall and intermediate classes for H1 (Table 2).

The height classes used for analysis of 2000 and 2003 data were defined by the 1999 unreplicated data. Some of these classifications did not agree with replicated data combined over years. None of the maturity group 00 accessions was as short or as tall for H2 as the extremes in groups II and IV in 2000 (Table 1). This contributed to the lack of differences between the intermediate and tall classes in maturity group 00. However, some accessions were as short or as tall for H2 as the extremes in group II and IV in 2003 (Table 1). The group IV accessions were the most consistent across years. Ten of 14 accessions in this group were consistently classified in same height class in each year. Although several accessions would not have been classified the same in 2000 and 2003 as in 1999, no accession shifted more than one class in 2000 and 2003. Short or tall accessions in 1999 may have been intermediate in either 2000 or 2003, and those in the intermediate class in 1999 may have been in any of the three classes in 2000 or 2003; however, no accession classified as short in 1999 was among the tallest in 2000 and 2003, and no accessions classified as tall in 1999 was among the shortest in 2000 and 2003 with one exception. PI 366122 was in the tall class in 1999 and 2000 but was among the shortest accessions in 2003 (Table 1). There was greater precipitation in 2000 and 2003 than in 1999, and spaced plants were measured in 2000 and 2003 rather than the hill plantings used in 1999. These and other environmental factors may have affected early plant height among the years. Comparing the *t* tests for all three measurements, these data indicate that the optimum time of evaluating early plant height is 30 d after planting (H2). The largest differences among classes occurred at this measurement when the means of tall, intermediate, and short classes were 78, 62, and 46 cm, respectively (Table 2). ANOVA results showed there was no significant interaction between year and height class on the basis of the data collected from 2000 and 2003. The means of tall, intermediate, and short classes in 2000 versus 2003 were 82 to 73, 67 to 57, and 47 to 46 cm, respectively. These data indicate that there were significant genetic differences among accessions.

The effects of maturity groups were not significant for H2 (Table 3). Examining the mean heights of all entries in each maturity group revealed that the overall height differences among maturity groups were generally small and not predictable (Table 3). For H1, lines in maturity group 00 and IV were the same height (17 cm) and group II lines were significantly taller (22 cm). For H3, maturity group 00 and II were not significantly different, but the group IV lines were significantly shorter (Table 3). Final maturity date was not a factor in determining early growth rates.

Table 3. Mean plant height of accessions within each maturity group for three times of measurement.

Maturity group	Height†		
	H1	H2	H3
	cm		
00	17 A‡	62 A	117 A
II	22 B	64 A	113 A
IV	17 A	60 A	103 B

† Three height measurements (H1, H2 and H3) were taken 20, 30, and 40 d after planting, respectively. H2 was the mean of 2000 and 2003 data.
‡ Means with the same letter within measurements are not significantly different (0.01 probability level).

Table 4. Early plant height means for accessions selected for extremes on the basis of data from 3 yr.

Accession	Origin	Height class	Maturity group	Height in1999 H2	Height in 2000† H1	H2	H3	Height in 2003 H2
				cm				
PI 507836	Russia	short	00	21	12	56	93	50
PI 479745	Jilin, China	short	II	15	6	35	75	33
PI 479750	Jilin, China	short	II	7	9	40	85	46
PI 407217	S. Korea	short	IV	18	6	18	73	27
PI 407200	S. Korea	short	IV	10	7	27	85	43
PI 468396B	Shanxi, China	short	IV	17	7	41	83	38
PI 507760	Russia	tall	00	68	22	77	130	68
PI 507841B	Russia	tall	00	60	23	78	134	74
PI 507794	Russia	tall	II	80	31	87	138	73
PI 468918	Liaoning, China	tall	II	80	45	88	142	70
PI 407032B	Japan	tall	IV	66	34	76	127	110
LSD $_{0.01}$					9.5	17.3	32.8	12.2

† Three height measurements (H1, H2, and H3) were taken 20, 30, and 40 d after planting, respectively.

The analysis of all 44 individual lines showed that LSD values at 0.01 significance level were 9.5, 17.3, and 32.8 cm for the three measurements (H1, H2 and H3) in 2000, and 12.2 cm for H2 in 2003, respectively (Table 1). Eleven lines were identified as short or tall types with significant differences between all short and tall lines at all three measurements in 2000 and for H2 in 2003 (Table 4). The tall and short lines were distributed among all the maturity groups tested. No accessions from Japan were among the short types and no accessions from S. Korea were among the tall types (Table 4). PI 407217, maturity group IV from South Korea, was the shortest line at 6 cm for H1 and 73 cm for H3 in 2000. The tallest accession was PI 468918, maturity group II from Liaoning, China, which was 45 cm for H1 and 142 cm for H3 in 2000. There was over a sevenfold difference for H1 and nearly a two-fold difference for H3 between the heights of these two lines.

To help understand what contributes to differences of plant height in early growth stages, growth rates of 28 lines that were consistently classified into one of the three height classes in 2000 were calculated for each of the three growth periods. A regression analysis was conducted using these growth rates to determine patterns of growth during the first 40 d. Differences in early plant height were established very quickly. The largest differences were observed during the first 20 d with the tall plants growing at a rate 3.5-times faster than the short plants (Table 5). Significant differences were still noted during the next 10-d period, but those differences disappeared between 30 and 40 d after planting.

Comparing three different regression models within each height class, the linear regression model was a poor fit for the data set from this study, indicating that the curve is other than a straight line. The residual sum of squares of the Logistic Growth Curve model had the smallest value for each of the three height classes so it was selected as the best representation of plant growth for these accessions. The three equations were presented as $Y_{(S)} = 1/(0.0095 + 5.515e^{-0.1962X})$, $Y_{(I)} = 1/(0.0082 + 3.102\ e^{-0.2025X})$, and $Y_{(T)} = 1/(0.0066 + 0.724\ e^{-0.1648X})$, where Y is the plant height, X is the days after planting, S is the short class, I is the intermediate class and T is the tall class. By comparing 95% confidence intervals of the three parameters in the three Logistics Growth Curve equations, it was found that two of the three parameters, b1 and b2, in the tall class were significantly different from the other two height classes (Table 6). Overlap existed between intermediate and short classes for all three parameters, indicating that the equations for these two height classes are not significantly different (Table 6).

Table 5. Growth rate means for 28 selected accessions in three height classes at three growth stages in 2000.

Height class	Number of lines tested	Growth rate (cm/day) 0–20 d	20–30 d	30–40 d
Short	11	0.4	3.2	4.4
Intermediate	6	0.8	4.8	4.5
Tall	11	1.5	5.5	4.7
LSD $_{0.01}$		0.2	0.8	1.4

Significant differences in early height among wild soybean accessions were identified. This rapid early growth could be a beneficial trait for the cultivated soybean and can be used for characterizing wild soybean germplasm. As reported by Mian et al. (1998), fast and vigorous early growth and rapid canopy development can be effective in suppressing weed infestation of crop plants. Furthermore, increased plant height is considered a desirable attribute for cultivars used for late planting in the south and for early maturity group soybean cultivars, since greater vegetative growth before flowering is considered an advantage for producing higher seed yield as well as more efficient mechanical harvest. This tallness is also recognized as a desirable trait for low-yielding environments where stress conditions limit plant growth (Walker and Cooper, 1982). Compared with data collected in wild soybean, cultivated soybean has less vigorous early growth. Two extreme parents, S-100 and Tokyo, were used in the experiment conducted by Mian et al. (1998) to create a population for mapping the QTL conditioning early growth in soybean. At theV7 stage, S-100 was 17 cm tall and Tokyo was 24 cm. At the V10 stage, S-100 and Tokyo had reached 30 and 35 cm, respectively. In wild soybean, the mean height for tall- and short-plant height classes were 29 and 11, 78 and 46, and 126 and 94 cm for the three measurements (H1, H2, and H3), respectively (Table 2). It may be possible to transfer this more rapid, early

Table 6. Values for parameters in the Logistic Growth Curve equation for the three height classes of 28 wild soybean accessions in 2000†.

	Parameter *b1*		Parameter *b2*		Parameter *b3*	
Class	**Estimate**	**95% confidence limits**	**Estimate**	**95% confidence limits**	**Estimate**	**95% confidence limits**
Short	**105**	**79–130**	**0.18**	**−0.20–0.56**	**0.20**	**0.12–0.27**
Intermediate	**120**	**114–128**	**0.31**	**0.09–0.54**	**0.20**	**0.17–0.23**
Tall	**153**	**140–166**	**1.37**	**0.58–2.25**	**0.16**	**0.14–0.19**

† Logistic Growth Curve equation: $Y = \frac{b_1}{1+[(b_1-b_2)/b_2]e^{-b_3X}} + \varepsilon$**, where b_1 is the height of the horizontal asymptote at a very large X; b_2 is the expected value of Y at time $X = 0$; b_3 is a measure of growth rate, and ε is the random error.**

growth from wild soybean into cultivated soybean, since this trait is not related to time of maturity.

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